How sensitive are predicted knee contact forces to the muscle recruitment criterion formulation?

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Introduction

Musculoskeletal modeling is an important tool to estimate knee contact forces in vivo. In these models, anatomical muscles are frequently sub-divided into smaller units to account for wide origin/insertion areas. However, the specific sub-division has been shown to affect some muscle recruitment criteria, especially used in inverse dynamic computations, and it has been suggested that normalization factors should be incorporated into models [1].

Therefore, the primary aim of this study was to investigate the effect of different muscle normalization factors in the polynomial muscle recruitment criterion on the estimated total, medial and lateral knee contact forces during gait. A secondary aim was to investigate the sensitivity of the predictions to the isometric strength of the knee flexor and extensor muscles.

Methods

Estimates of the medial, lateral and total knee contact force were evaluated on three different musculoskeletal models with increasing levels of patient-specificity and knee joint model complexity for one subject from the Grand Challenge data set and evaluated against measured tibiofemoral contact forces. The models were developed in the AnyBody Modeling System (AnyBody Technology, Denmark) based on the models presented by Marra et al [2] and included a linearly scaled model, a patient-specific model with a hinge knee and a patient-specific model with a Force-dependent Kinematics knee.

For each model, estimates of the loads were obtained by 1) no normalization, 2) normalizing with the number of muscle elements and 3) normalizing with the muscle volume. These were evaluated with polynomial orders of 2-4.

For the secondary aim, the strength of the knee flexor and extensor muscles were reduced from 100 % to 40 % in steps of 10 %.

Results

Normalizing by the number of muscle elements or the volume lowered the estimated contact forces compared to no normalization and with the effect being more pronounced with a polynomial order of two and minor for four.

The secondary investigation revealed that the predicted forces can vary substantially as a function of the knee flexor and extensor muscle strength with over one body weight smaller forces in the predicted total contact force for 40 % of the muscle strength as compared to 100 %.

Discussion

The primary result imply that caution should be taken when a normalization factor is introduced to account for sub-divided muscles especially for second-order recruitment criteria. The secondary result is important as in vivo measurements of tibiofemoral contact forces are obtained from a patient group that is known to have reduced knee flexor and extensor strength and this could suggest that higher forces are present in a healthy population.

References

[1] Holmberg LJ, Klarbring A. 2012. Multibody Syst Dyn. 28(3): 283–289.

[2] Marra MA et al. 2015. J. Biomech Eng. 137 (2): 020904.